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ENTRANCE HEAD

IN

PIPES AND CONDUITS

BY

WASHINGTON PARKER IRELAND

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

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June 1, 1903

This is to certify that the thesis prepared under the supervision of Professor Talbot by WASHINGTON PARKER IRELAND, entitled ENTRANCE HEAD IN PIPES AND CONDUITS, is approved by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

Ira O Baker

Head of Department of Civil Engineering

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Entrance Head In Pipes And Conduits.

It is a well established fact that the shape and condition of the entrance or inlet to pipes and conduits affect their discharging capacity. If the end of the pipe projects into the water, the discharge will be less than when the end is flush with the wall of the reservoir. Pipes provided with bell-shaped or conical mouthpieces will give a greater discharge than flush-end or inward projecting pipes. It is likewise true that the loss of head at entrance, for a pipe discharging a certain amount, varies with the shape of the entrance to the pipe.

These principles were established by hydraulicians who made experiments to determine the effect of different conditions and shapes of approaches on the discharge from cylindrical pipes. An examination of these experiments reveals the fact that they were all made with pipes of small diameter, varying in most cases from 1/2-in. to 2-in. The results of these experiments may not be applied to large pipes used for water distribution, suction pipes, conduits, and pipes of large diameter, such as are used to conduct water through railroad embankments and under highways.

Pipes through embankments, or culverts as they are called, are usually provided with approaches consisting of walls, the form and position of which affect the discharge. Walls making an angle of divergence with the axis of the pipe cause a discharge different from that produced by walls parallel to

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the axis. A straight wall at right angles to the axis of the pipe causes a discharge differing from that in both the above cases.

Since the results of the experiments made by hydraulicians with pipes of small diameter may not be applicable to pipes of large diameter, it was believed that an investigation of the flow through larger pipes would be a contribution to hydraulic knowledge, and would also throw light on the discharging capacity and losses of head in pipes of still larger sizes.

Before entering into this investigation, it will be well to review the theoretical explanation of the flow of water through pipes.

Flow Through Pipes.

The total head which causes flow of water through pipes is absorbed in three ways, viz., (1) by contraction, resistance of the inner edge at entrance, and expansion of the section just within the pipe, together called entrance head, (2) by imparting velocity to the water, and (3) by overcoming the resistance due to friction. This may be represented by the equation $h = \frac{v^2}{2g} + m\frac{v^2}{2g} + f\frac{l}{d}\frac{v^2}{2g}$ in which h is the total head on the center of the down-stream end of the pipe, $\frac{v^2}{2g}$ is the amount of h used to impart velocity to the water, $m\frac{v^2}{2g}$ is the amount of h taken by contraction, resistance of the inner edge of the pipe at entrance, and expansion to the full size of the pipe, and $f\frac{l}{d}\frac{v^2}{2g}$

is that part of h used in overcoming friction. The term v is the average velocity of the issuing stream in feet per second. The average velocity is used because the actual velocity varies in different parts of the section considered. For a short horizontal pipe, the velocity in the lower part is greater than that in the upper part, since it is under a higher head. Near the side of the pipe the velocity is less than near the center, the smaller value being due to friction. The term g is the acceleration of gravity. m is the coefficient for the entrance head. f is the coefficient of friction. l is the length of the pipe in feet. d is the diameter of the pipe in feet.

The loss due to friction $f\frac{l}{d}\frac{v^2}{2g}$, is small in short tubes, as is seen by the following demonstration. In an experiment with a 12-in. pipe three diameters in length, a head of 1.00 ft. gave an actual velocity of 5.6 ft. per second. The velocity head corresponding to this is .71 The water, after contraction, fills the pipe at a distance of two diameters from the entrance. Hence l, the length of that part of the pipe flowing full, = 1 ft., d = 1 ft. The friction factor f = .02 (see Merriman's "Treatise on Hydraulics" - Page 168) Substituting these values, $f\frac{l}{d}\frac{v^2}{2g} = .02 \times 1 \times .71 = .014$
The loss due to friction is therefore about 1.4% in this case. The term $f\frac{l}{d}\frac{v^2}{2g}$ will therefore be dropped for pipes of three diameters length, and the friction loss will be included in the term for entrance head $m\frac{v^2}{2g}$. We shall use the formula $h = (1+m)\frac{v^2}{2g}$. The coefficient of entrance head m is obtained from $m = (\frac{1}{c^2}-1)$ (see Merriman's Treatise on Hydraulics-Page 165, Art. 73), in which c is the coefficient

of discharge, or velocity, determined by dividing the actual discharge of a short tube by the theoretical discharge.

The real problem is to determine the loss of head at entrance, $m\frac{v^2}{2g}$, with different shaped approaches, and under different conditions. After a careful search of existing literature on this subject, it is thought that the following results are all that have been published.

		C. of Dis.
Hamilton Smith. (published 1886.)	Deductions made from results of other experiments - Cyl. pipe, mouth flush with side of reservoir --	.825
	Cyl. pipe, in. proj., sharp edges --	.715
	Bell shaped m.p., small vel. --	.950
	" " " " very high vel. --	.995
Michelotti.	Tubes 1½" to 3" in diameter under heads varying from 3' to 20' gave as mean value of c --	.813
Buff.	With tube .02" in diam., as head decreased from 2.8' to 0.1' c var. from	.825-.855
Bidone.	Tube with diam. = .13', l = .22	.767
Weisbach. (1846)		.815
Merriman. (1889-98)	In. Projecting tube --	.721
	Flush end --	.82
	Bell shaped or perfect m.p.	1.00

To determine the loss of head at entrance, $m\frac{v^2}{2g}$, with different shaped approaches, a number of experiments were made with 6-in. and 12-in. cylindrical pipes, each about three diameters in length. From these experiments the coefficients of discharge, c, were determined by dividing the actual discharge by the theoretical. The coefficients were then inserted in the equation $m = (\frac{1}{c^2} - 1)$.

Experiments With Six Inch Pipe.

A cylindrical cast-iron pipe, 22-1/2 in. in length and 6-in. in diameter, bored to an accurate caliber, was used for these experiments. The pipe had threads cut in each end, and was provided with a flange near the center containing bolt holes. (see Plate 1.) Seven diverging mouthpieces were provided, and threads cut in them to fit the ends of the pipe. These mouthpieces each made a different angle of divergence from the axis of the pipe, and were of a length necessary to make the area of the larger end twice that of the pipe. (see Plate 2.) A board, 3/8 in. in thickness and five diameters square, with a hole in the center to fit the end of the pipe, was also used, called "straight wall" in the experiments. The pipe was placed in a horizontal position with one end protruding from an orifice in the side of a water-tight box. As the water rose in the box, the head on the center of the pipe was indicated by the height of water in a small vertical glass tube on the outside, the lower end of which was connected with the interior of the box. The water discharged from the pipe was measured

Plate I.

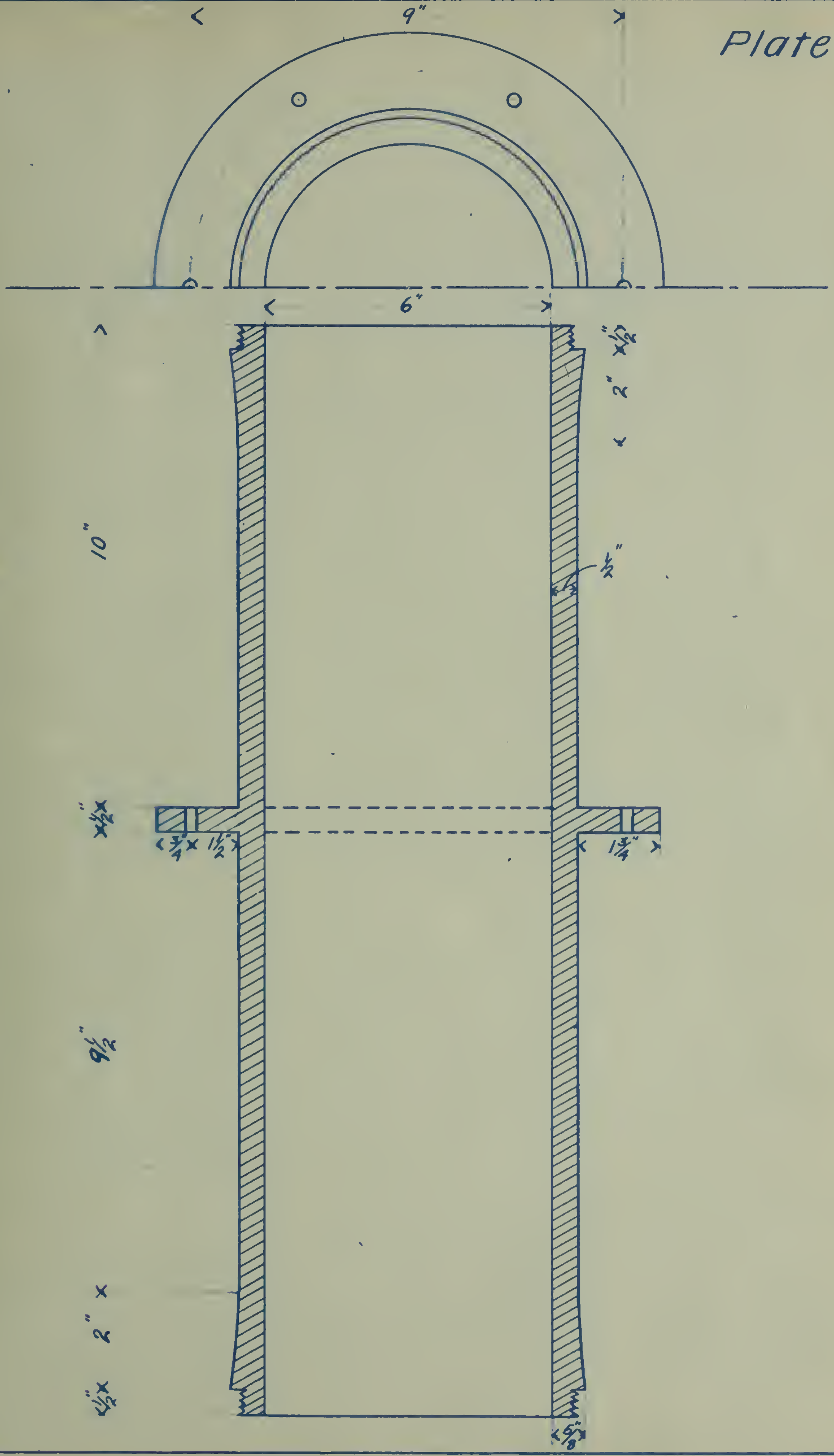
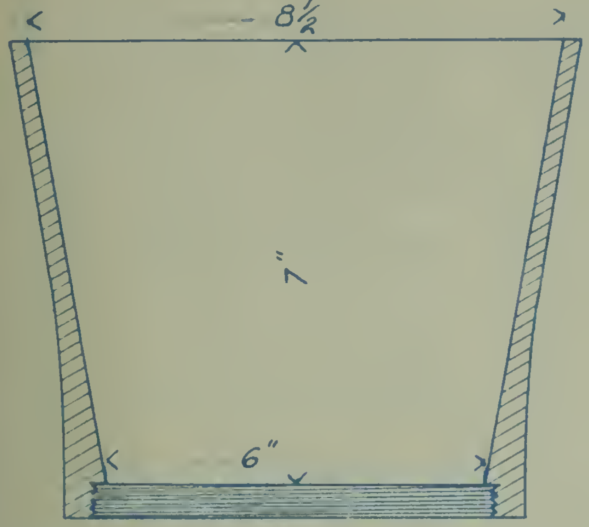
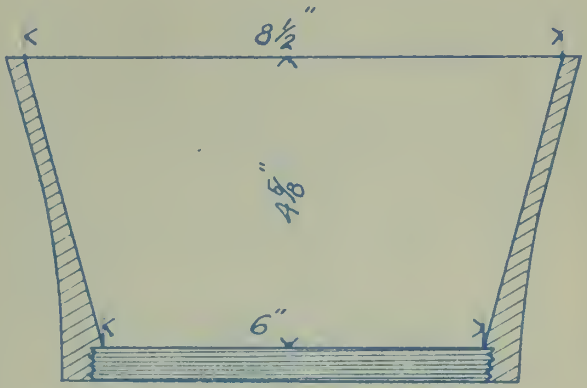
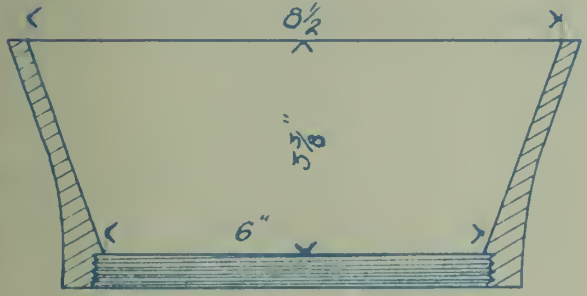
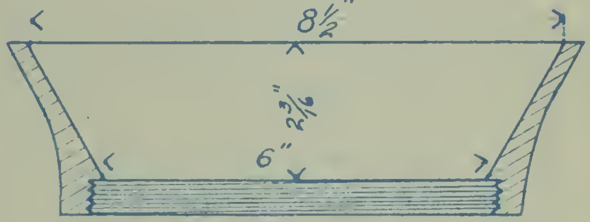


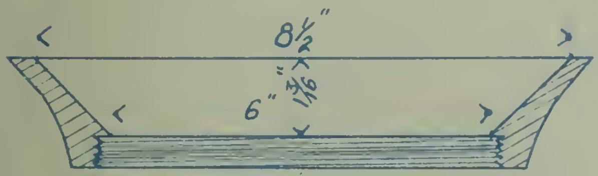
Plate 2.

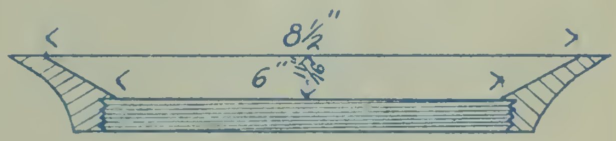


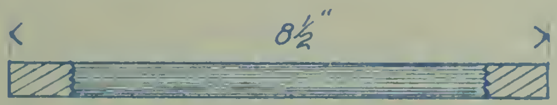










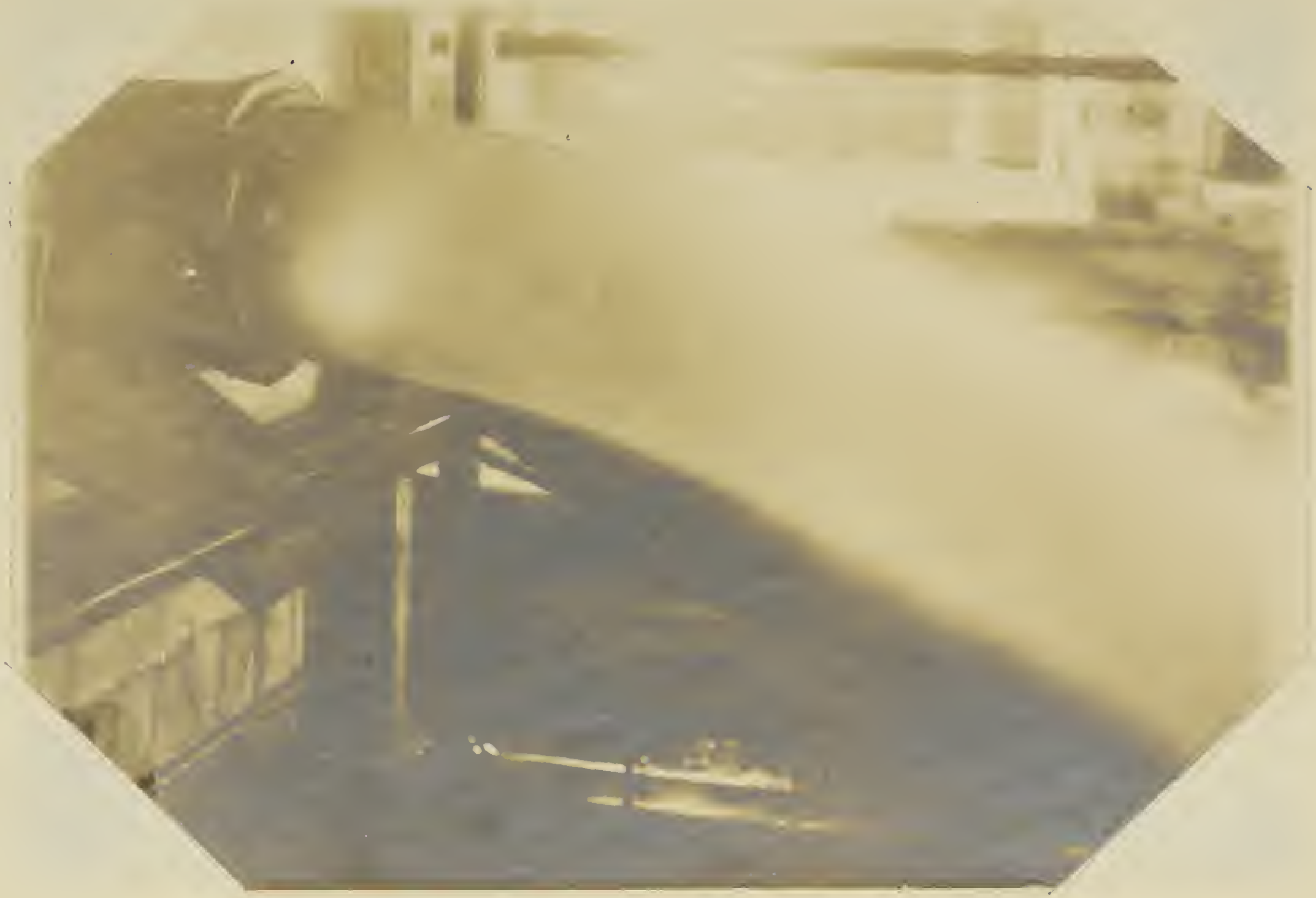


in a pit below, 5.96 ft. in diameter and 5 ft. in depth. The rise of water in the pit was indicated by the movement of an iron rod attached to a float in the water, a pointer on the rod marking the number of feet rise on a level rod graduated to feet, tenths, and hundredths.

A set of experiments was made with each mouthpiece on the inner end of the pipe, a set comprising tests made with the center of the pipe under from three to five different heads. Each experiment was repeated as a check. The water discharging from the pipe (see Plate 3) was first conveyed by means of a waste pipe to another pit, until the head on the center of the pipe became constant. The waste pipe was then withdrawn, and the time of entrance of the water into the measuring pit was obtained by means of a stop watch. When the pit was about full, the water was again diverted from it by means of the waste pipe, and the time of diversion caught with the stop watch. The rise of water in the pit was measured with the float described above, the rod being read to hundredths of a foot. Knowing the diameter, and hence the cross section of the pit in square feet, the rise of water in the pit in feet, and the time of rise in seconds, the actual discharge from the pipe in cubic feet per second was computed.

In making these experiments the rod used to measure the rise of water in the pit was read to the nearest .01 ft., the probable variations in readings being less than .005 ft. The greatest error caused by this would occur when the smallest rise, 1.95 ft., was read. The maximum error due to this cause then is .26%.

=PLATE 3=



To get the area of the pit the mean of a number of diameters was used, the diameters being measured with a tape to the nearest .01 ft. The error due to inaccuracy in measurement for the number of measurements taken was therefore very small. The mean diameter of the pit was 5.96 ft. The maximum error due to variation in cross section at different levels is probably less than .2%

To obtain the head on the center of the pipe the gauge was read to the nearest millimeter with a probable maximum variation in reading of 1 mm. or .003 ft. The largest error occurred when the lowest head .30 ft. was read. This may be 1%.

The time was taken with a stop watch to the nearest 1/5 second. The largest variation then was .1 second. The shortest time taken was 40 seconds, in which there may be an error of .25%.

Combining the opportunities for error in the different observations, it is believed that the greatest error possible in the final results is less than 1-1/2%, and that the average error is probably much less than 1%. The number of observations for each condition was so small that no effort was made to apply the mathematical principles of probable error.

The results of the experiments performed as described above are given in the table which follows, together with the theoretical discharge, coefficient of discharge c, and coefficient of entrance loss $\overset{m}{X}$, for each experiment. The theoretical discharge was calculated from the equation $Q = a\sqrt{2gh}$, in which Q is the theoretical discharge in cubic feet per sec-

ond, g is the acceleration of gravity, and h is the head in feet on the center of the pipe. The coefficient of discharge (c) was obtained by dividing the actual discharge by the theoretical. The coefficient of entrance loss (m) was calculated from $m = (1/c^2 - 1)$, in which c is the coefficient of discharge. The velocity of the water in the pipe was obtained from $q = av$, in which q = the actual discharge in cubic feet per second, a = area of the pipe in square feet, and v = velocity of the water in feet per second.

In the following table data above dotted line is for pipe not flowing full at discharge end. Below dotted line pipe flows full at discharge end.

=TABLE 2=

6-inch pipe - Discharging with air.
Discharge measured in Pit.

Ref. No.	Mouth-piece.	Head on Pipe in Feet.	Time in Sec.	Rise in Pit in Feet.	Act. Discharge in Cu. Ft. per Sec.	Theo. Discharge $a\sqrt{2gh}$ in Cu. Ft. per Sec.	Av. Act. Velocity in Ft. per Sec.	Coef. of Discharge C.	Coef. of Ent. Loss m.
1	Inward Project.	.30	155	2.27	.408	.861	2.08	.47	3.53
2		.32	155	2.40	.432	.889	2.20	.48	3.34
3		.46	154	3.04	.550	1.065	2.80	.52	2.70
4		.47	145	2.99	.575	1.078	2.92	.53	2.56
5		.63	113	2.83	.698	1.248	3.55	.56	2.19
6		.63	105	2.62	.695	1.248	3.54	.56	2.19
7		.78	87	2.47	.791	1.388	4.02	.57	2.08
8		.78	105	2.98	.791	1.388	4.02	.57	2.08
9		.79	111	3.18	.799	1.397	4.07	.57	2.08
10		1.14	60	2.80	1.301	1.679	6.61	.77	.69
11		1.16	63	2.88	1.274	1.693	6.46	.75	.77
12		1.78	49	2.92	1.661	2.097	8.44	.79	.60
13		1.79	57	3.31	1.620	2.103	8.24	.77	.69
14		1.84	57	3.39	1.658	2.132	8.43	.78	.64
15	Straight Wall.	.26	132	1.83	.387	.802	1.98	.48	3.34
16		.31	159	2.55	.447	.876	2.30	.51	2.84
17		.42	115	2.86	.693	1.018	3.51	.68	1.16
18		.44	108	2.92	.754	1.042	3.82	.72	.93
19		.47	121	2.66	.613	1.078	3.11	.57	2.08
20		.47	111	2.41	.605	1.078	3.08	.56	2.19
21		.61	101	2.54	.701	1.227	3.57	.57	2.08
22		.61	124	3.14	.706	1.227	3.60	.58	1.97
23		.76	103	2.99	.809	1.371	4.13	.60	1.78
24		.80	98	2.93	.833	1.405	4.21	.60	1.78
25		.81	108	2.64	.682	1.415	3.49	.48	3.34
26		.82	103	3.13	.847	1.424	4.31	.59	1.87
27		1.11	67	3.17	1.318	1.655	6.70	.80	.56
28		1.14	65	3.12	1.338	1.679	6.80	.80	.56
29		1.76	54	3.29	1.699	2.086	8.66	.81	.52
30		1.79	52	3.17	1.698	2.103	8.66	.81	.52

1	2	3	4	5	6	7	8	9	10
31		.47	121	2.50	.576	1.078	2.92	.53	2.56
32		.48	132	2.44	.515	1.089	2.62	.47	3.53
33		.50	158	2.43	.605	1.111	3.08	.54	2.43
34.	Ring.	1.11	81	3.79	1.304	1.657	6.62	.79	.60
35		1.15	72	3.44	1.330	1.685	6.73	.79	.60
36		1.74	66	3.87	1.635	2.073	8.31	.79	.60
37		1.81	66	3.99	1.685	2.114	8.60	.80	.56
38		.45	92	2.62	.794	1.054	4.03	.75	.77
39		.46	100	2.88	.803	1.065	4.11	.75	.77
40	10° Conical Tip.	1.11	61	3.29	1.504	1.657	7.61	.91	.21
41		1.14	56	3.08	1.533	1.679	7.80	.91	.21
42		1.79	41	2.82	1.917	2.103	9.79	.91	.21
43		1.84	44	3.08	1.952	2.132	9.98	.92	.18
44		.39	119	3.27	.766	.982	3.91	.78	.64
45		.48	120	3.61	.839	1.089	4.28	.77	.69
46		.64	76	2.63	.965	1.257	4.90	.77	.69
47		.64	82	2.91	.989	1.257	5.02	.79	.60
48		.66	89	3.34	1.046	1.276	5.30	.82	.49
49	15° Conical Tip.	.79	66	3.10	1.309	1.397	6.66	.94	.13
50		.81	60	2.80	1.301	1.415	6.60	.92	.18
51		1.13	65	3.63	1.557	1.671	7.91	.93	.16
52		1.14	63	3.56	1.575	1.679	8.00	.94	.13
53		1.74	50	3.44	1.918	2.073	9.78	.93	.16
54		1.76	50	3.46	1.929	2.086	9.87	.92	.18
55		1.82	50	3.49	1.946	2.121	9.92	.92	.18
56		.43	105	2.86	.759	1.031	3.87	.74	.83
67		.46	120	3.45	.802	1.065	4.08	.75	.77
58		.61	84	3.04	1.009	1.227	5.10	.82	.49
59		.66	73	2.72	1.039	1.276	5.28	.82	.49
60	20° Conical Tip.	.66	65	2.38	1.021	1.276	5.20	.80	.56
61		.78	71	3.24	1.272	1.388	6.47	.92	.18
62		.79	68	3.14	1.287	1.397	6.56	.92	.18
63		1.10	62	3.37	1.515	1.649	7.70	.92	.18
64		1.12	61	3.29	1.504	1.663	7.64	.90	.23
65		1.77	45	3.08	1.908	2.097	9.72	.91	.21
66		1.85	47	3.29	1.952	2.138	9.98	.91	.21

1	2	3	4	5	6	7	8	9	10
67		.46	95	2.50	.734	1.065	3.75	.69	1.10
68		.46	84	2.25	.747	1.065	3.80	.70	1.04
69	30° Conical Tip.	1.12	163	3.46	1.531	1.663	7.80	.92	.18
70		1.13	57	3.17	1.551	1.671	7.90	.93	.16
71		1.74	45	3.09	1.914	2.073	9.75	.92	.18
72		1.81	40	2.75	1.917	2.114	9.77	.91	.21
73		.28	120	1.99	.462	.831	2.38	.55	2.30
74		.42	152	3.67	.673	1.018	3.42	.66	1.32
75		.44	145	3.42	.657	1.042	3.33	.63	1.52
76	45° Conical Tip.	1.10	67	3.60	1.496	1.649	7.60	.91	.21
77		1.11	65	3.50	1.501	1.655	7.62	.90	.23
78		1.14	55	2.86	1.446	1.679	7.37	.86	.35
79		1.15	64	3.45	1.503	1.685	7.64	.89	.26
80		1.76	53	3.50	1.841	2.084	9.39	.88	.29
81		1.76	54	3.59	1.853	2.084	9.25	.89	.26
82		1.76	54	3.68	1.900	2.084	9.70	.91	.21
83		.44	115	2.70	.655	1.042	3.33	.63	1.52
84		.45	110	2.60	.659	1.054	3.38	.62	1.60
85	60° Conical Tip.	1.14	62	3.27	1.470	1.679	7.46	.88	.29
86		1.14	64	3.42	1.490	1.679	7.58	.89	.26
87		1.84	52	3.47	1.860	2.132	9.45	.87	.32
88		1.86	47	3.21	1.904	2.144	9.71	.89	.26
89	Straight Wall. (10° Conical Tip on Outer End.)	.43	139.5	2.80	.560	1.031	2.86	.54	2.43
90		.44	135	2.81	.580	1.042	2.94	.55	2.31
91		1.13	94.5	3.36	.991	1.671	5.04	.59	1.87
92		1.14	74	2.60	.980	1.679	5.00	.58	1.97
93		1.74	64	2.81	1.224	2.073	6.23	.59	1.87
94		1.76	69	3.06	1.236	2.084	6.28	.59	1.87
95		1.77	66	2.93	1.238	2.097	6.29	.59	1.87
96		1.79	70	3.12	1.242	2.103	6.31	.59	1.87

These results indicate that for heads small as compared with the diameter of the pipe, the coefficient of discharge is small, and the entrance loss is large. This is explained by the fact that the water in the lower part of the pipe, being under a comparatively much greater head than in the upper part, acquires a greater velocity than that at the top. On account of this difference in velocity, the amount of water entering the pipe at the top is less than that entering at the bottom. Since less water enters at the top than at the bottom the amount is insufficient to fill the pipe, and the water falls as shown in Fig. 1 and in photograph on Plate 7. As soon as the pipe is filled, the contraction becomes less, but is greater at the top of the pipe than at the bottom, as is shown in Fig. 2.

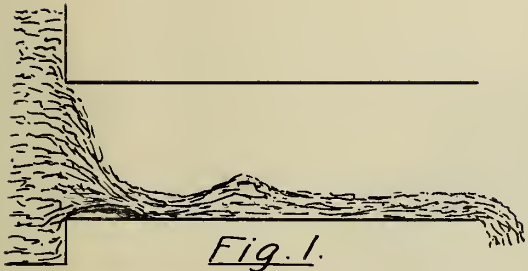


Fig. 1.

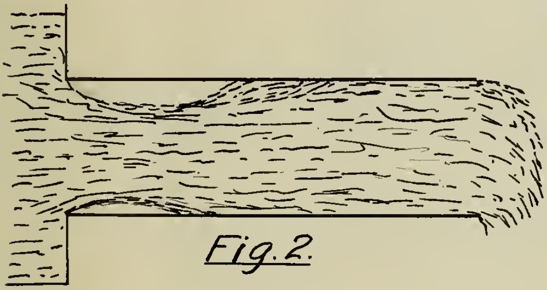
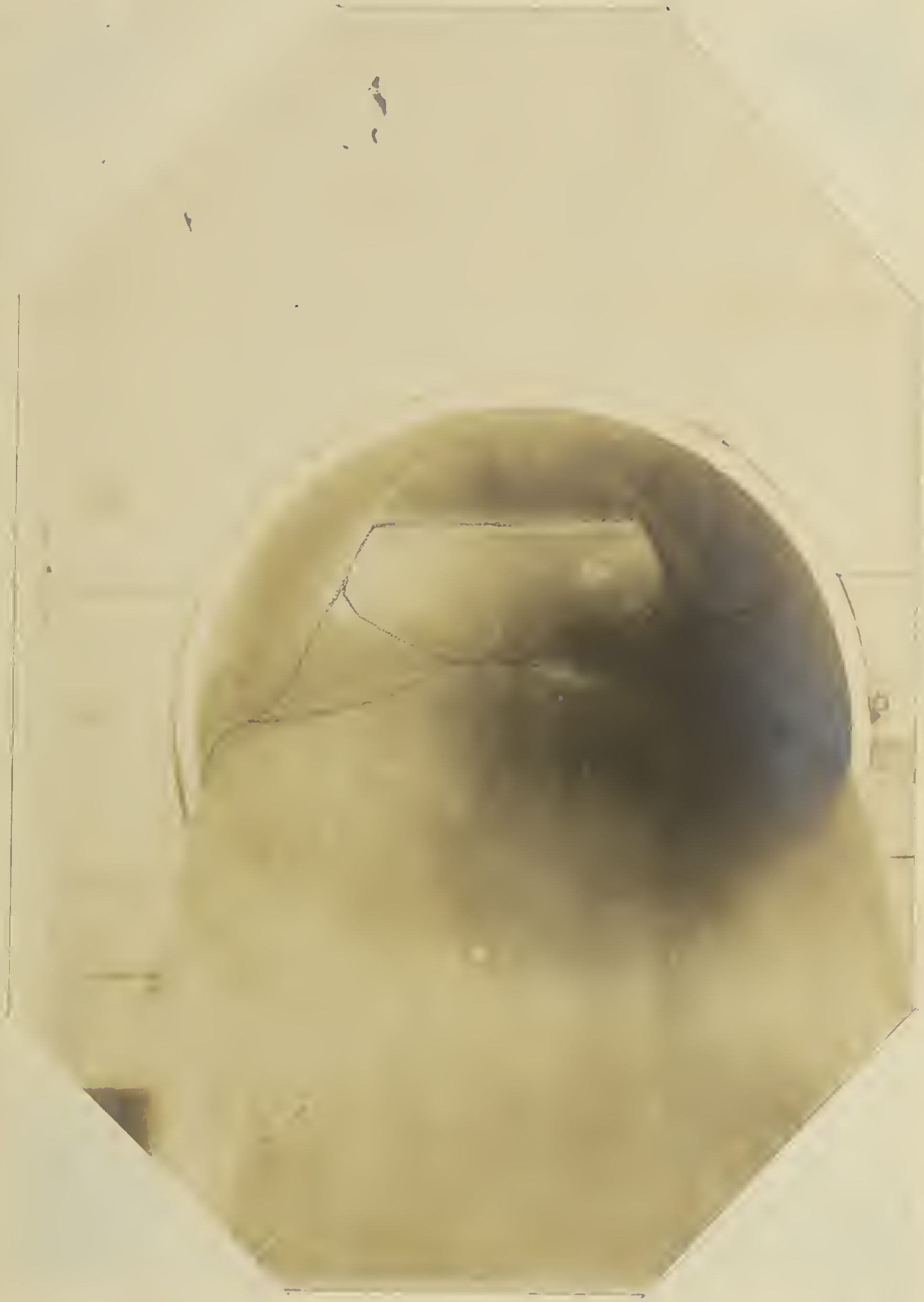


Fig. 2.

An attempt was made to prove this explanation by placing the pipe in a vertical position through a hole in the bottom of a water-tight box, and allowing the water to enter the pipe from beneath the box, issuing from it as a vertical jet. In this manner it was thought that an equal head could be obtained over the entire mouth of the pipe. This method of measurement was found to be inaccurate, since there was a pressure of the falling water of the jet upon that leaving the pipe, and hence the effective orifice of the pipe was in reality above the end and its proper position could not be determined. Using the head on the upper

=PLATE 7=



end of the pipe in the calculation of m, much larger values were obtained than in the former experiments, and it was easily seen that the conditions of these experiments made the results of no value.

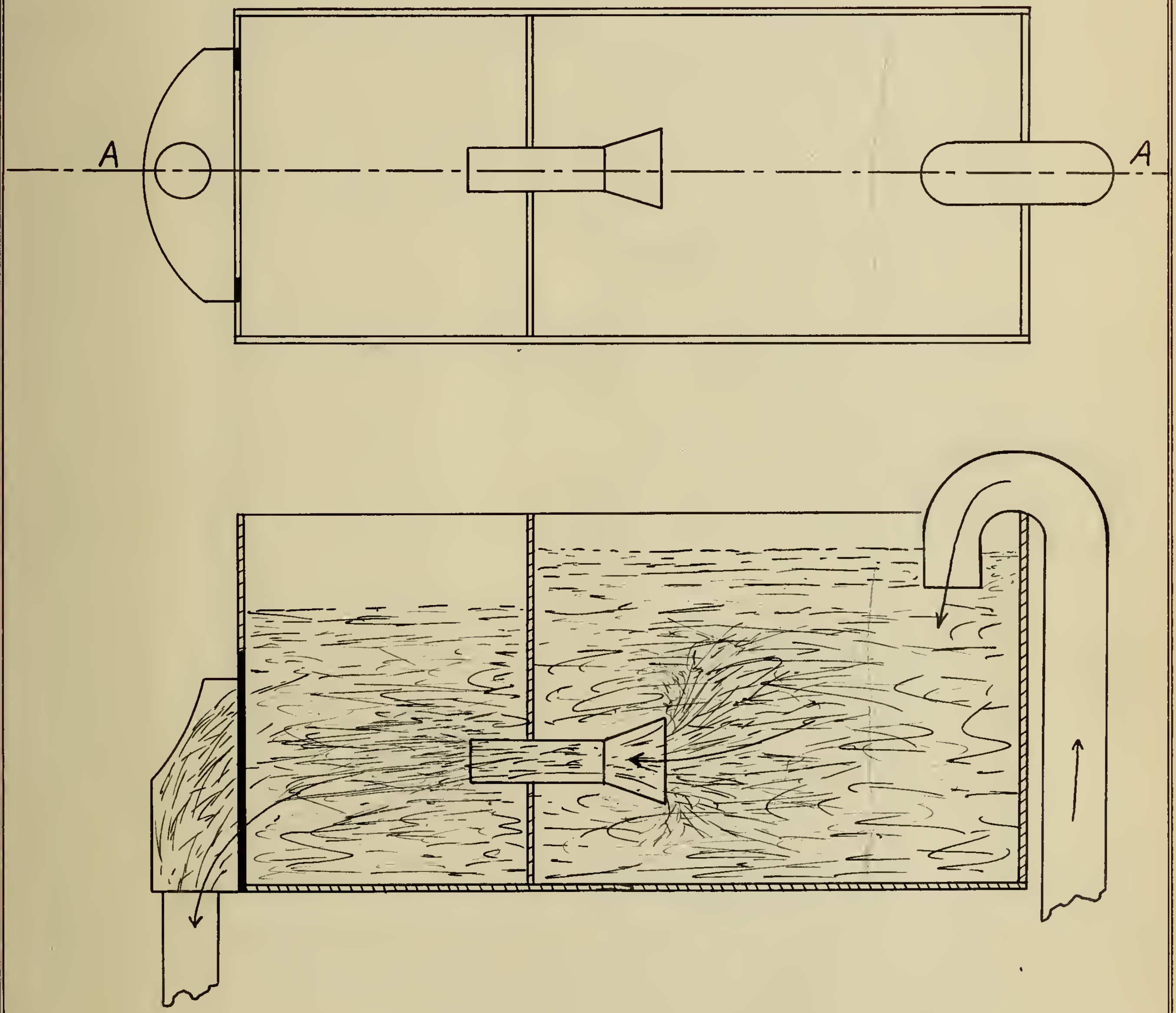
In order to get the effect of low heads and small velocities, experiments were made with the 6-in. pipe submerged, in a horizontal position. These experiments were made in a water-tight box divided into two compartments by a wall, through which the pipe protruded (see Plate 8). The water discharged from the box through two vertical rectangular openings, the flow being equally distributed vertically, and the level of the water in the box being kept at any desired height by means of baffle boards placed over the openings. The difference in level of the water on the upper and lower end of the pipe was obtained by means of two gauges similar to that used in the former experiments, one placed near the upper end of the pipe, the other near the lower end. The water was conveyed from the box by means of a waste pipe to a weir channel, where the flow was measured over a 3 ft. suppressed weir. The same apparatus was used as in the former experiments, and the results obtained are given in the table which follows: It will be seen that the values of m obtained at low heads are nearly the same as for high heads.

=TABLE 3=

6 inch pipe – submerged
Discharge measured over 3 ft weir

Ref. No.	Mouth-piece.	Head on Pipe in Feet.	Head on Weir in Feet.	Act. Dis. $c\frac{2}{3}\sqrt{2g}bH^{\frac{3}{2}}$ in Cu.Ft. per Sec.	Theo. Dis. $a\sqrt{2gh}$ in Cu.Ft. per Sec.	Av. Act. Veloc. in Ft. per Sec.	Coef. of Discharge C.	Coef. of Ent. Loss m.
1	Straight Wall.	.125	.119	.432	.556	2.20	.78	.64
2		.125	.119	.432	.556	2.20	.78	.64
3		.35	.173	.745	.916	3.79	.81	.52
4		.35	.174	.751	.916	3.82	.82	.49
5		1.04	.253	1.299	1.603	6.59	.81	.52
6		1.04	.253	1.299	1.603	6.59	.81	.52
7	Ring.	.16	.132	.498	.629	2.55	.79	.60
8		.16	.132	.498	.629	2.55	.79	.60
9		.30	.161	.671	.861	3.41	.78	.64
10		.30	.162	.678	.861	3.45	.79	.60
11		.99	.248	1.264	1.564	6.40	.81	.52
12		.99	.248	1.264	1.564	6.40	.81	.52
13	Inward Projecting	.10	.107	.372	.497	1.90	.75	.78
14		.10	.105	.362	.497	1.83	.73	.87
15		.33	.162	.678	.678	3.45	.75	.78
16		.33	.161	.671	.671	3.41	.74	.82
17		1.00	.246	1.248	1.572	6.31	.79	.60
18		1.00	.247	1.258	1.572	6.38	.80	.56
19	15° Conical Tip.	.10	.110	.388	.497	1.99	.78	.64
20		.10	.109	.383	.497	1.95	.77	.68
21		.25	.162	.678	.786	3.45	.88	.29
22		.25	.163	.684	.786	3.48	.87	.32
23		1.02	.277	1.492	1.588	7.59	.94	.13
24		1.02	.276	1.481	1.588	7.52	.93	.15

=PLATE 8=



Experiments With Twelve Inch Pipe.

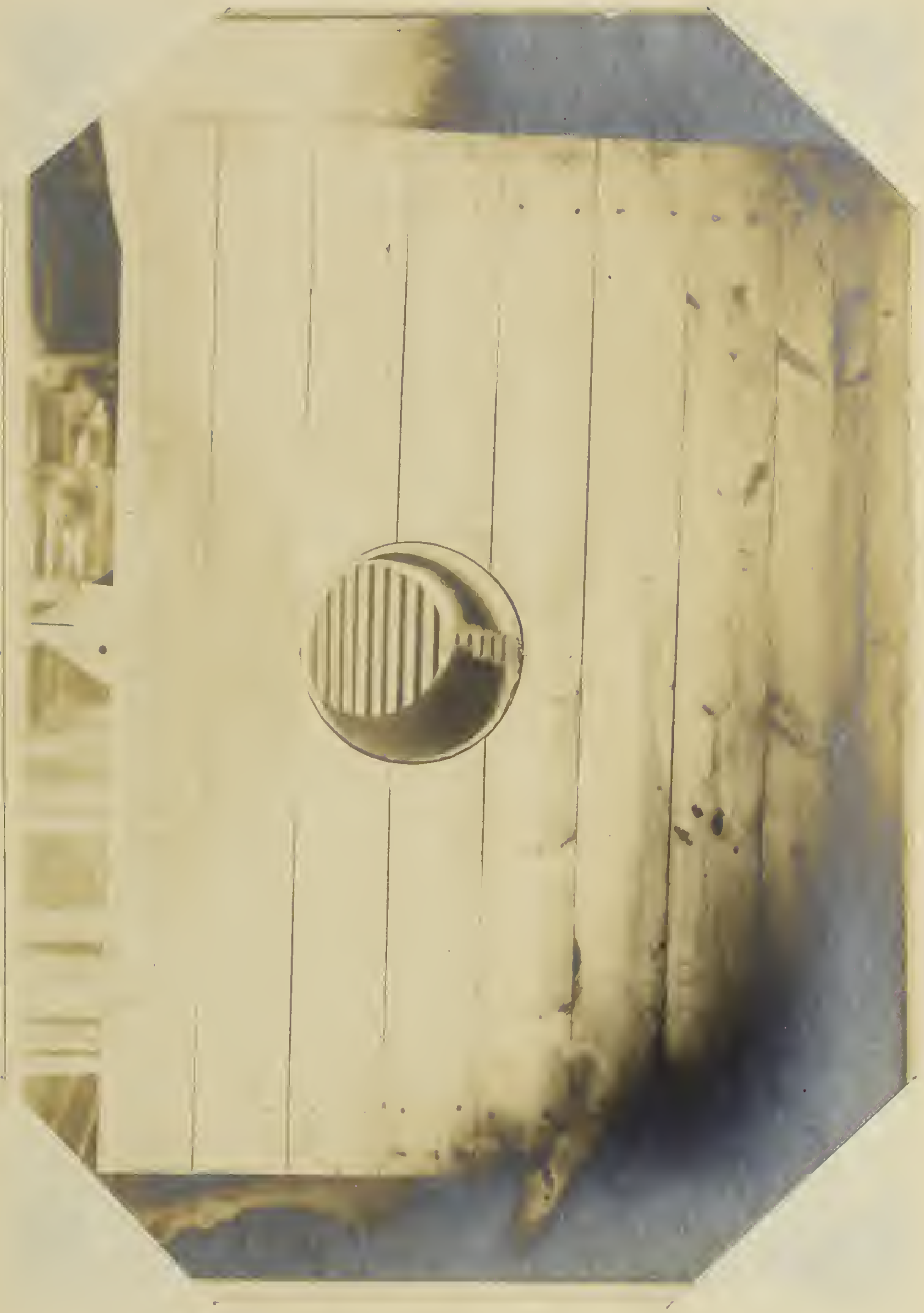
For these experiments a wrought-iron cylindrical pipe, 12-in. in diameter and 36-in. in length was used. The pipe was provided with straight wall and wing-wall entrance, (see Plates 4 and 5) built of dressed and matched flooring. The straight wall was so constructed that the distance from the edge of the pipe to the top, bottom, and sides of the wall was 2 diameters. The wing-walls were built so that they could be swung on hinges to any desired angle with the axis of the pipe. (For diagrams see Plate 6).

The pipe was placed in a horizontal position in a large weir channel, with one end protruding through a hole in a water tight bulkhead built across the weir opening, and the other end, supporting one of the above described wall entrances, resting on an A support. The water entered the channel at the upper end and was discharged through the pipe. The head on the center of the pipe was measured by means of the level rod used in the experiments with the 6-in. pipe. The rod was placed at the side of the channel near the end of the pipe and the height of water read to hundredths of a foot. After discharging from the pipe, the water passed over a 3 ft. suppressed weir. The actual discharge was measured by means of this weir, the head on the weir being obtained with a hock gauge.

A set of experiments was made with the wing-walls making angles of 0°, 15°, 30° and 45° with the axis of the pipe. Another set was made with the straight wall entrance perpendicular to the axis of the pipe, the end of the pipe being flush with the wall.

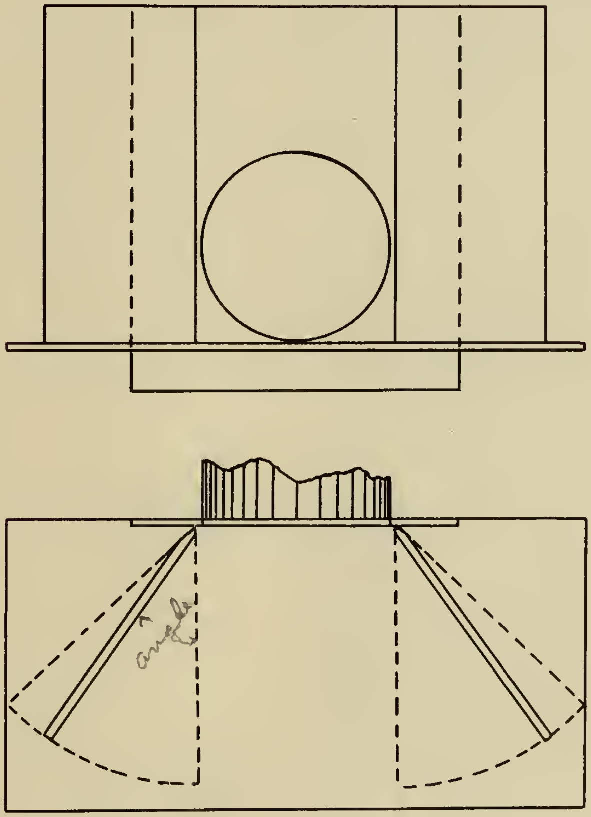
= PLATE 4 =

12 - in Pipe



=PLATE 5=

=PLATE 6=



The table which follows gives the results of the above described experiments, together with the theoretical discharge, coefficient of discharge, coefficient of entrance loss, and actual velocity, for each experiment. The theoretical discharge was obtained from the equation $Q = a\sqrt{2gh}$. The actual discharge over the weir was obtained from $q = c\frac{2}{3}\sqrt{2gh}\,bH^{\frac{3}{2}}$, in which q = actual discharge in cubic feet per second, c = coefficient of discharge for the weir, b = length of weir in feet, and H = head on weir in feet. The velocity was obtained from q = av, the equation used for the same purpose in the other experiments with the 6-in. pipe. The coefficient of discharge and coefficient of entrance loss were determined as before.

=TABLE 4=

12 inch pipe - Discharging into air

Discharge measured over 3 ft. weir.

Ref. No.	Entrance.	Head on Pipe in Feet.	Head on Weir in Feet.	Act. Dis. $c\frac{2}{3}\sqrt{2g}bH^{\frac{3}{2}}$ in Cu. Ft. per Sec.	Theo. Dis. $a\sqrt{2gh}$ in Cu. Ft. per Sec.	Av. Act. Veloc. in Ft. per Sec.	Coef. of Dis-charge C.	Coef. of Ent. Loss m.
1	Inward Projecting	.57	.371	2.298	4.727	2.92	.49	3.16
2		.78	.432	2.883	5.530	3.66	.52	2.69
3		.96	.558	4.239	6.131	5.40	.69	1.10
4	Straight Wall. 90°	.80	.502	3.614	5.600	4.59	.65	1.37
5		.98	.566	4.332	6.201	5.51	.70	1.04
6		1.00	.574	4.423	6.256	5.65	.71	.98
7		1.31	.681	5.724	7.160	7.29	.80	.56
8		.54	.370	2.289	4.594	2.92	.50	3.00
9	0° Wing Walls.	.73	.462	3.085	5.351	3.92	.58.	1.97
10		.93	.508	3.676	6.037	4.67	.61	1.69
11		1.23	.661	5.474	6.942	6.98	.79	.60
12	15° Wing W'lls.	.62	.411	2.675	4.930	3.41	.54	2.43
13		.84	.476	3.374	5.741	4.30	.59	1.88
14		1.25	.659	5.449	6.997	6.92	.78	.60
15	30° Wing W.	.57	.395	2.518	4.727	3.20	.53	2.56
16		.86	.478	3.350	5.803	4.28	.58	1.97
17		1.21	.639	5.196	6.887	6.61	.76	.73
18	45° Wing W.	.58	.392	2.487	4.766	3.17	.52	2.69
19		.80	.462	3.188	5.600	4.07	.57	2.08
20		.92	.488	3.462	5.998	4.40	.58	1.97
21		1.11	.611	4.861	6.599	6.20	.74	.83

Data above dotted line is for pipe not flowing full at discharge end. Below dotted line discharge end is full.

Conclusions.

The effect of varying the shape of the entrance to pipes on the coefficient of entrance loss is illustrated by the diagrams on Plate 19.

From the data given the following deductions may be made:

1. There is not much difference between the values of m for the inward projecting pipe, the pipe flush with wall of reservoir (straight wall), and the pipe with a ring mouthpiece. Generally for pipes flowing full at the discharge end the values of m may, without great error, be taken to be .50 for flush end, .56 for ring mouthpiece, and .62 for inward projecting pipe. For low heads or low velocities it may be somewhat larger.

V = 6 to 9 flowing full

2. The values of m for diverging mouthpieces do not differ much from each other. For angles of divergence of from 10° to 30°, m may be taken to be .20, and from 30° to 60° it may be .25

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3. Pipes provided with diverging mouthpieces have much smaller values of m than inward projecting pipes, flush ends, cr ring ends.

4. In the construction of pipe culverts through railroad embankments and under highways, a minimum loss of head at entrance and a maximum discharge may be obtained by building conical mouthpieces with an angle of divergence of 10° to 30° with the axis of the pipe.

5. If culverts are constructed with wing-wall entrances, there is not much difference in the values of m for different degrees of divergence. With the pipe flowing full m varies from

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one exp. only in each angle of divergence

.60 to .80 with any angle of divergence between 0° and 90°, including straight wall or flush end. So far as shown, then, the discharging capacity is practically independent of the form of entrance. Wing-walls may be advantageous in directing the flow of drift and rubbish through the culvert.

The discharge from pipes not flowing full at the discharge end is materially less than that usually calculated, due to the dropping of the water or contraction at entrance, and to the error in the velocity assumed. The value of m, using v as the velocity, calculated from full pipe section in the formula $h = (1+m)\frac{v^2}{2g}$, will be from 3 to 6 times the value found for conditions for the pipe actually running full. If the actual average velocity in the part-full pipe was used, the resulting value of m would not be far from the amounts given in deductions 1 and 2. In order that a short pipe may flow full and discharge the amount calculated by the usual formula, the head on the center of the pipe must be at least one diameter.

Under low heads pipes of any length will not flow full unless submerged at the discharge end as shown in Fig. 3.

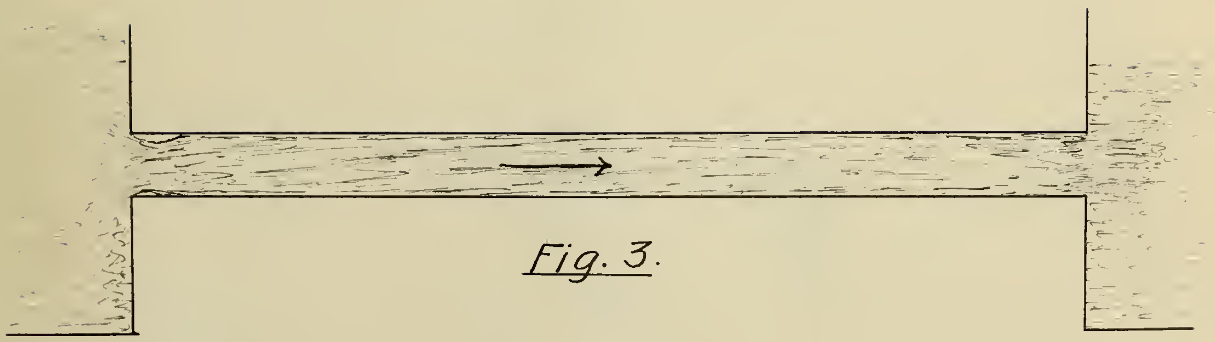

Fig. 3.

Under this condition the values of m are about as given in deductions 1 and 2. see table 3 page 18

Having obtained the coefficient of discharge for pipes of three diameters length the discharging capacity of pipes of any length may be calculated by means of the formula $V=\sqrt{\frac{2gh}{1+m+f\frac{l-3d}{d}}}$, (see Merriman's Treatise on Hydraulics, Page 180). Using the values of m from Table 4 formulas for discharge through culverts with the discharge end flowing full are as follows:

St. Wall Entrance.

For $l=3d$, $V=.80\sqrt{2gh}$.
" $l=12d$, $V=.75\sqrt{2gh}$.
" $l=24d$, $V=.71\sqrt{2gh}$.

In. Proj. Entrance.

For $l=3d$, $V=.78\sqrt{2gh}$.
" $l=12d$, $V=.74\sqrt{2gh}$.
" $l=24d$, $V=.71\sqrt{2gh}$.

15° Wing Walls.

For $l=3d$, $V=.79\sqrt{2gh}$.
" $l=12d$, $V=.75\sqrt{2gh}$.
" $l=24d$, $V=.71\sqrt{2gh}$.

From Merriman —
Standard Short Tube.

For $l=3d$, $V=.82\sqrt{2gh}$.
" $l=12d$, $V=.77\sqrt{2gh}$.
" $l=24d$, $V=.73\sqrt{2gh}$.

There is little difference between the discharge for the different ends.

It may be seen by the diagrams on Plate 19 that when the discharge end does not flow full, m ranges from 1.5 to 3.0 The values of c corresponding to these values of m are .63 and .50 respectively. We therefore have the following equation by which the discharge may be calculated, $q = .50 \text{ to } .63\, a\sqrt{2gh}$.
Thus we see that the discharge from pipes not flowing full at the discharge end is about 2/3 that from the pipes flowing full. Using the above equation the following values of q were obtained:

Straight Wall.

For $l = 3d,\ q = .63\, a\sqrt{2gh}$.
„ $l = 12d,\ q = .61\, a\sqrt{2gh}$.
„ $l = 24d,\ q = .58\, a\sqrt{2gh}$.

Inward Proj.

For $l = 3d,\ q = .52\sqrt{2gh}$.
„ $l = 12d,\ q = .51\sqrt{2gh}$.
„ $l = 24d,\ q = .49\sqrt{2gh}$.

or 30° or 45°

15° Wing Walls.

For $l = 3d,\ q = .54\, a\sqrt{2gh}$.
„ $l = 12d,\ q = .52\, a\sqrt{2gh}$.
„ $l = 24d,\ q = .51\, a\sqrt{2gh}$.

The above equations were derived considering no velocity in the water at entrance to pipe. Assuming a velocity of approach of 1/2 the velocity in the pipe the following equations were derived from $V=\sqrt{\frac{2gh}{\frac{3}{4}+m+f\frac{l-3d}{d}}}$, for the pipe flowing full and partially full:

Pipe Flowing Full at Discharge End.

Straight Wall.	Inward Proj.
For $l=3d$, $V=.89\sqrt{2gh}$.	For $l=3d$, $V=.85\sqrt{2gh}$.
.. $l=12d$, $V=.84\sqrt{2gh}$.	.. $l=12d$, $V=.80\sqrt{2gh}$.
.. $l=24d$, $V=.77\sqrt{2gh}$.	.. $l=24d$, $V=.75\sqrt{2gh}$.

15° Wing Wall.

For $l=3d$, $V=1.02\sqrt{2gh}$.
.. $l=12d$, $V=.94\sqrt{2gh}$.
.. $l=24d$, $V=.85\sqrt{2gh}$.

Pipe Not Full at Discharge End.

St. Wall.	In. Project.
For $l=3d$, $V=.66\sqrt{2gh}$.	For $l=3d$, $V=.54\sqrt{2gh}$.
.. $l=12d$, $V=.64\sqrt{2gh}$.	.. $l=12d$, $V=.52\sqrt{2gh}$.
.. $l=24d$, $V=.61\sqrt{2gh}$.	.. $l=24d$, $V=.50\sqrt{2gh}$.

15° Wing W.

For $l=3d$, $V=.56\sqrt{2gh}$.
.. $l=12d$, $V=.55\sqrt{2gh}$.
.. $l=24d$, $V=.53\sqrt{2gh}$.

The number of experiments given here is comparatively small but it is thought that the results given are quite accurate. Among the most important results of this investigation are the advantages of conical mouthpieces and the small discharging capacity of culverts not flowing full at the discharge end. It appears that the latter is here stated for the first time. This field of investigation is a very broad one and still contains room for further research.

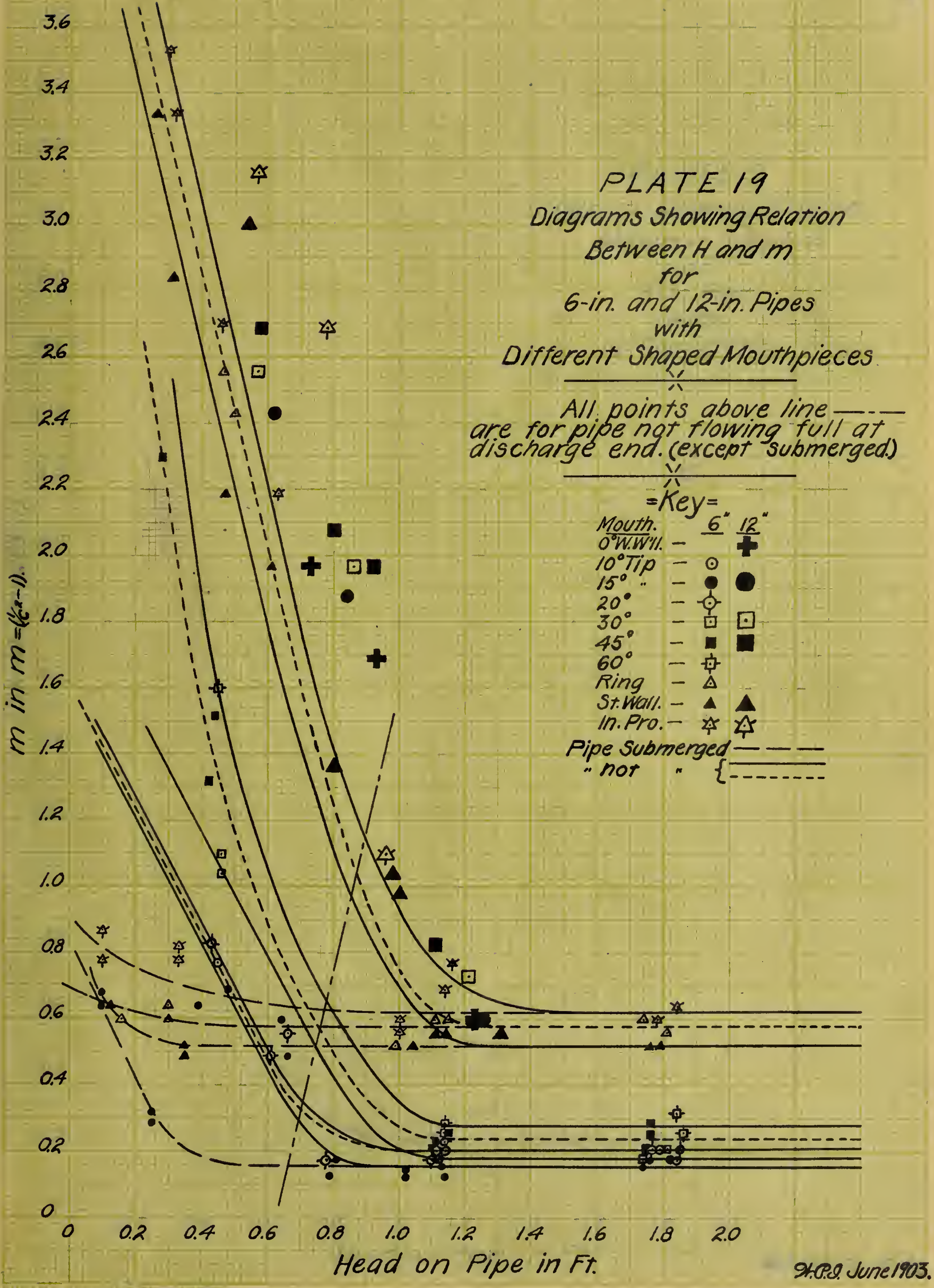

PLATE 19

Diagrams Showing Relation Between H and m for 6-in. and 12-in. Pipes with Different Shaped Mouthpieces

All points above line —·— are for pipe not flowing full at discharge end. (except submerged.)

H.P.G. June 1903.

CHICAGO.

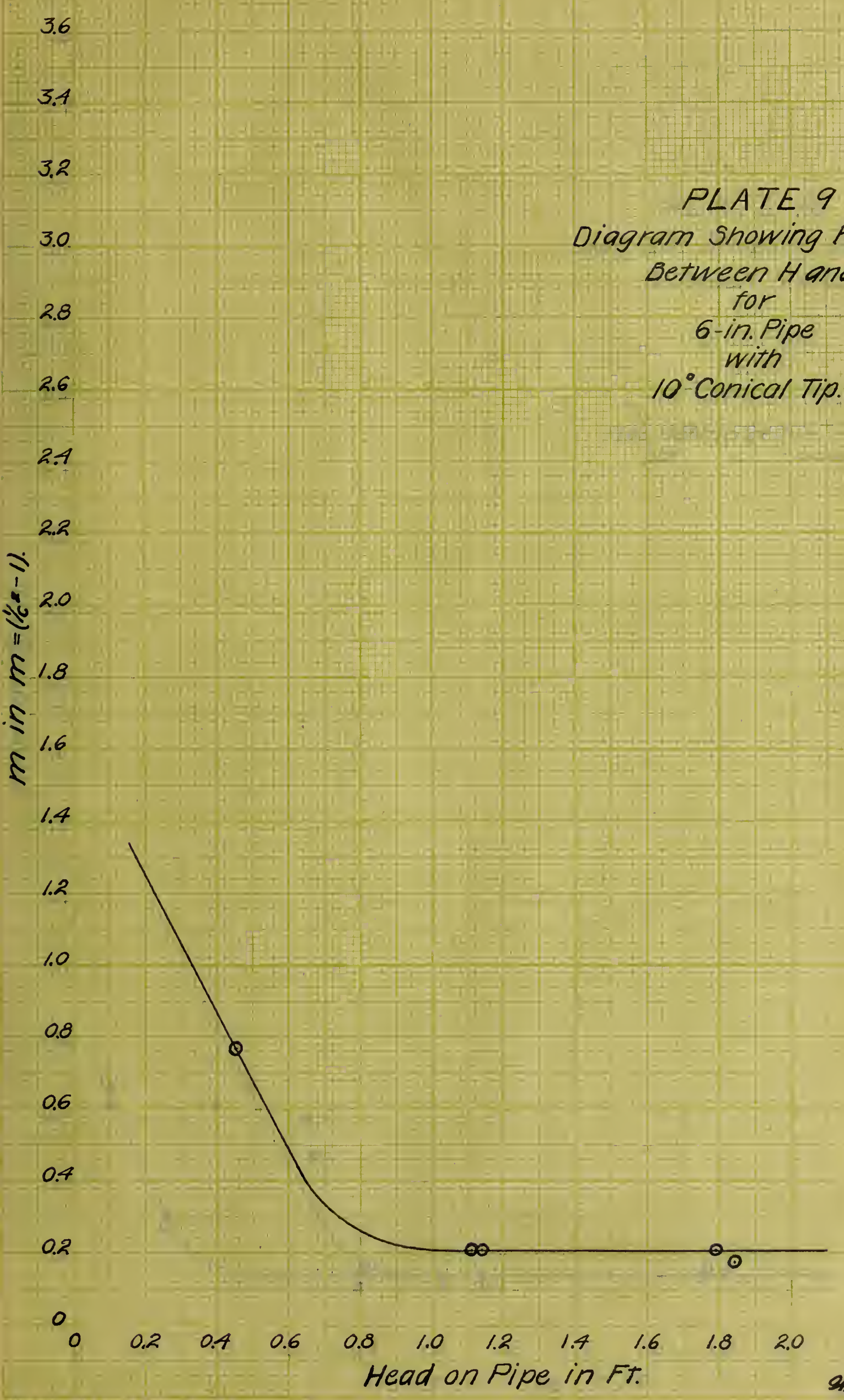

PLATE 9
Diagram Showing Relation
Between H and m
for
6-in. Pipe
with
10° Conical Tip.

H.O.J. June 1903.

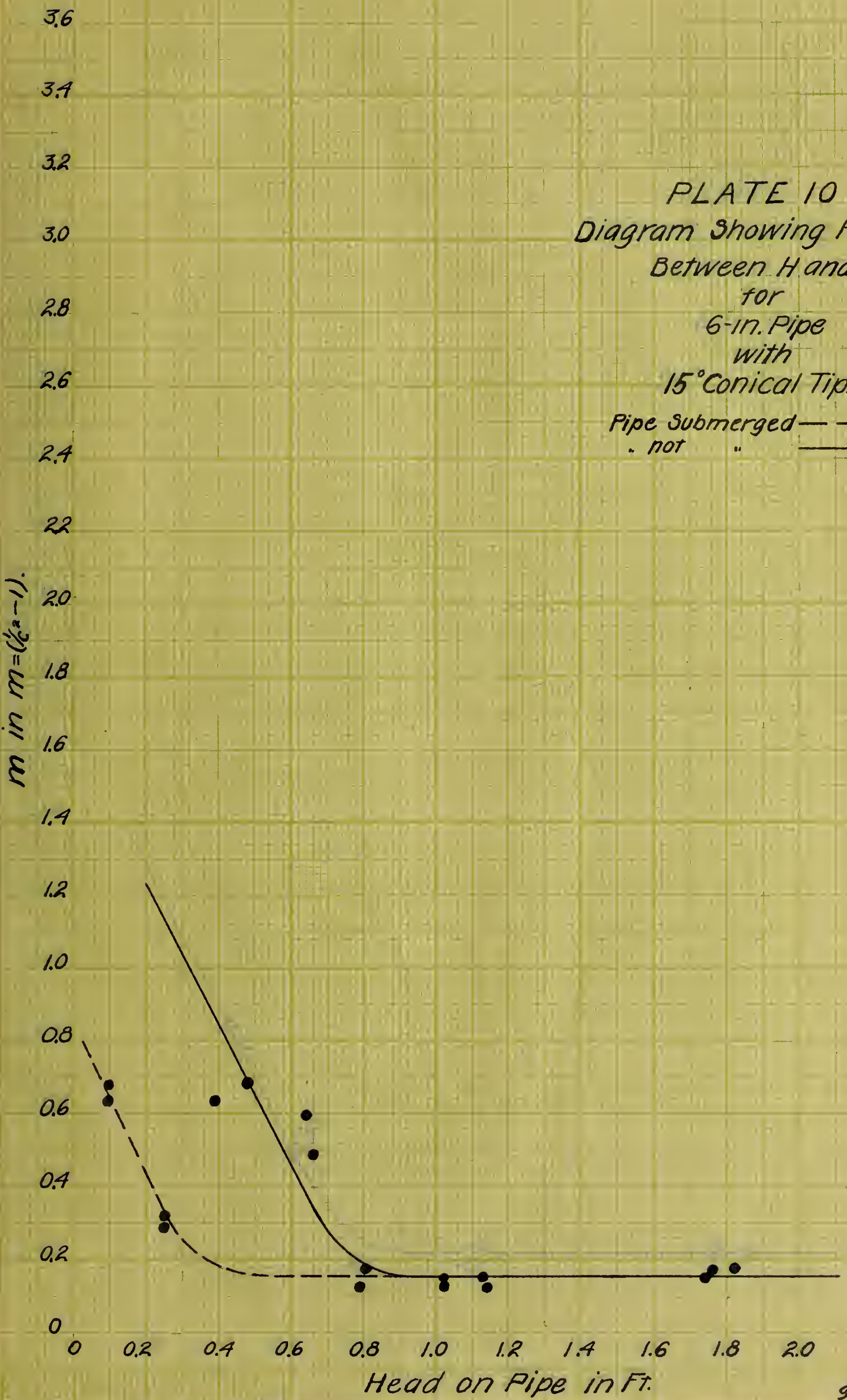

PLATE 10
Diagram Showing Relation
Between H and m
for
6-in. Pipe
with
15° Conical Tip.

H.P.S. June 1903.

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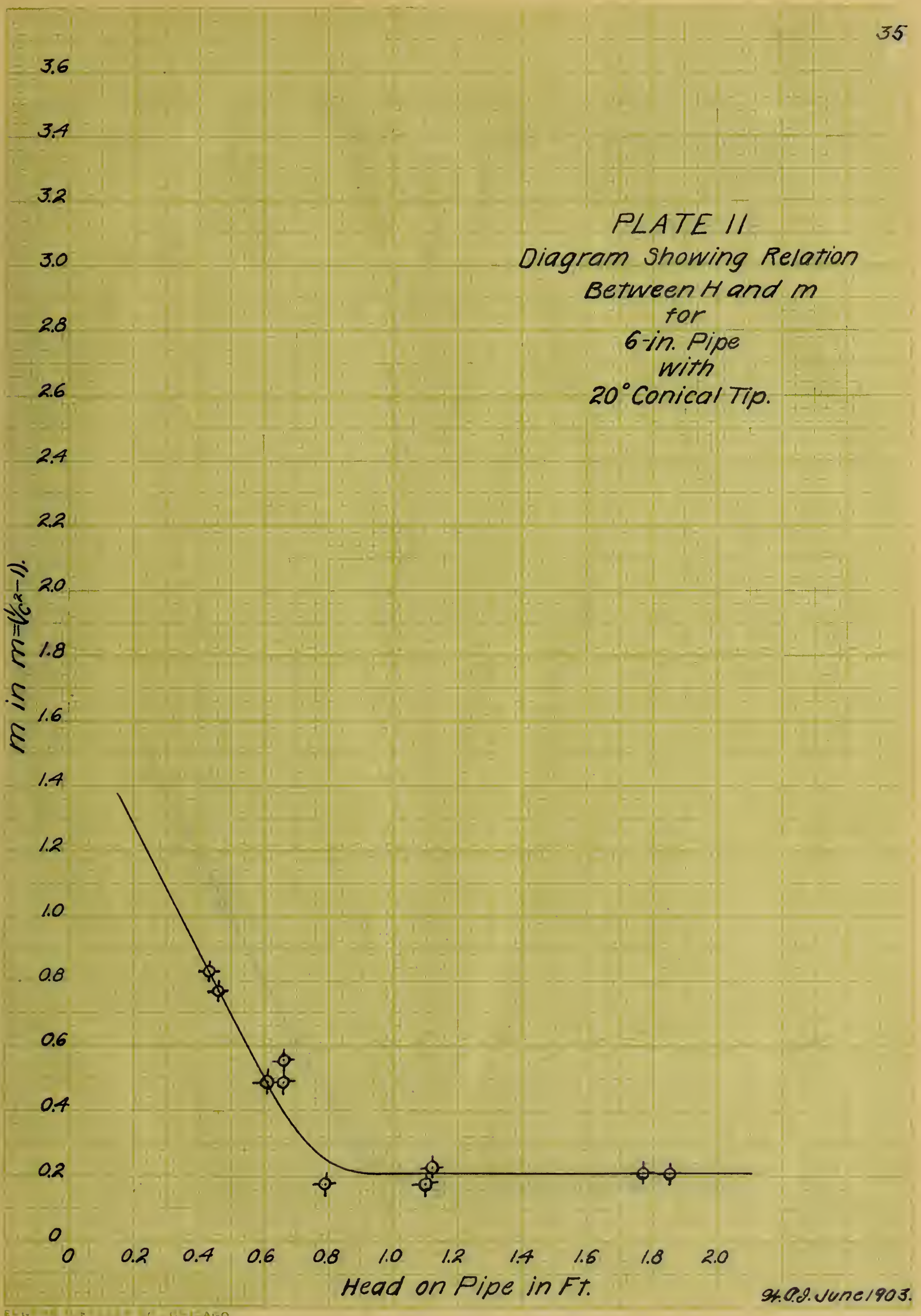

PLATE II
Diagram Showing Relation
Between H and m
for
6-in. Pipe
with
20° Conical Tip.

H.O.J. June 1903.

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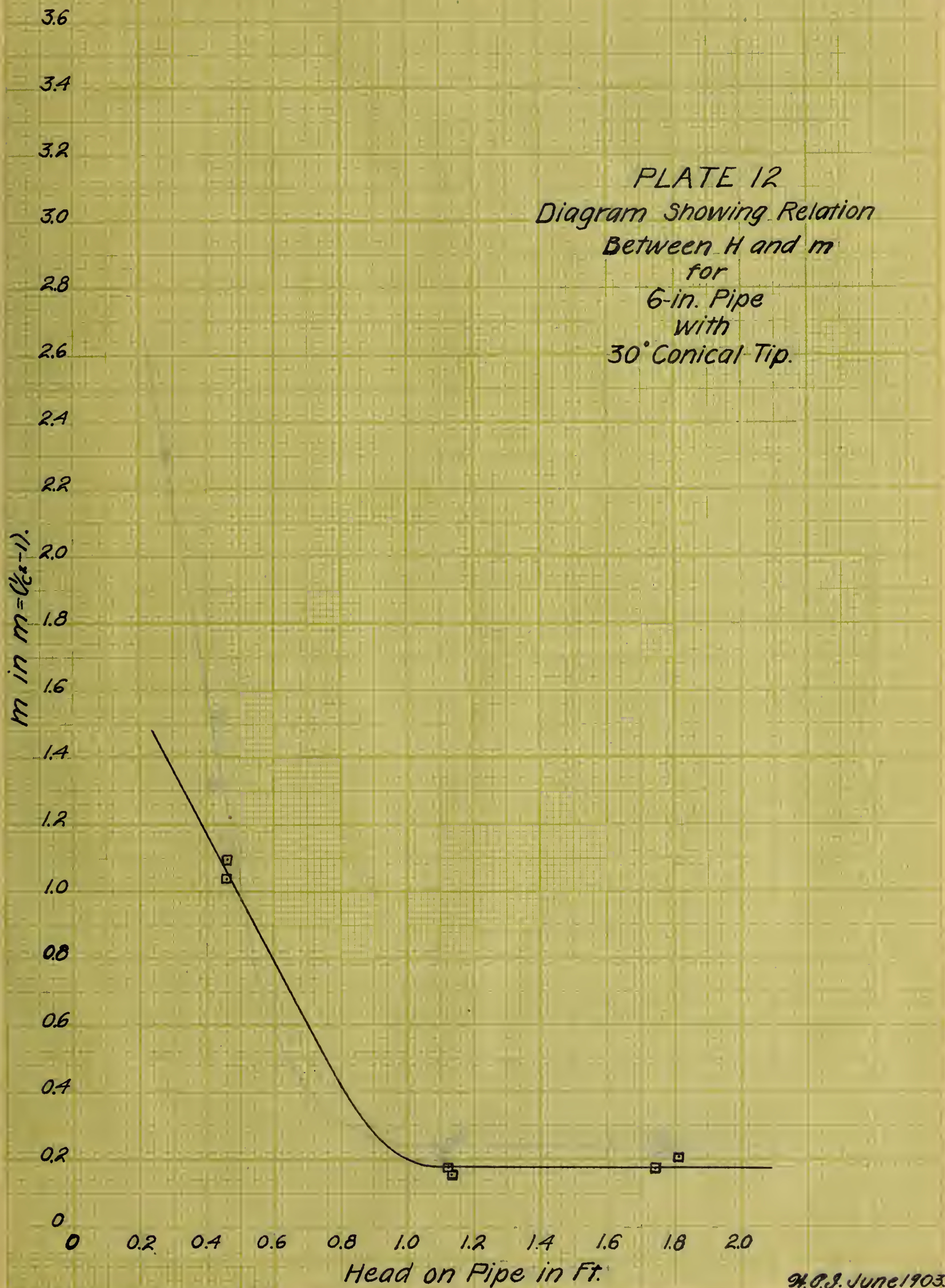

PLATE 12

Diagram Showing Relation Between H and m for 6-in. Pipe with 30° Conical Tip.

H.O.J. June 1903.

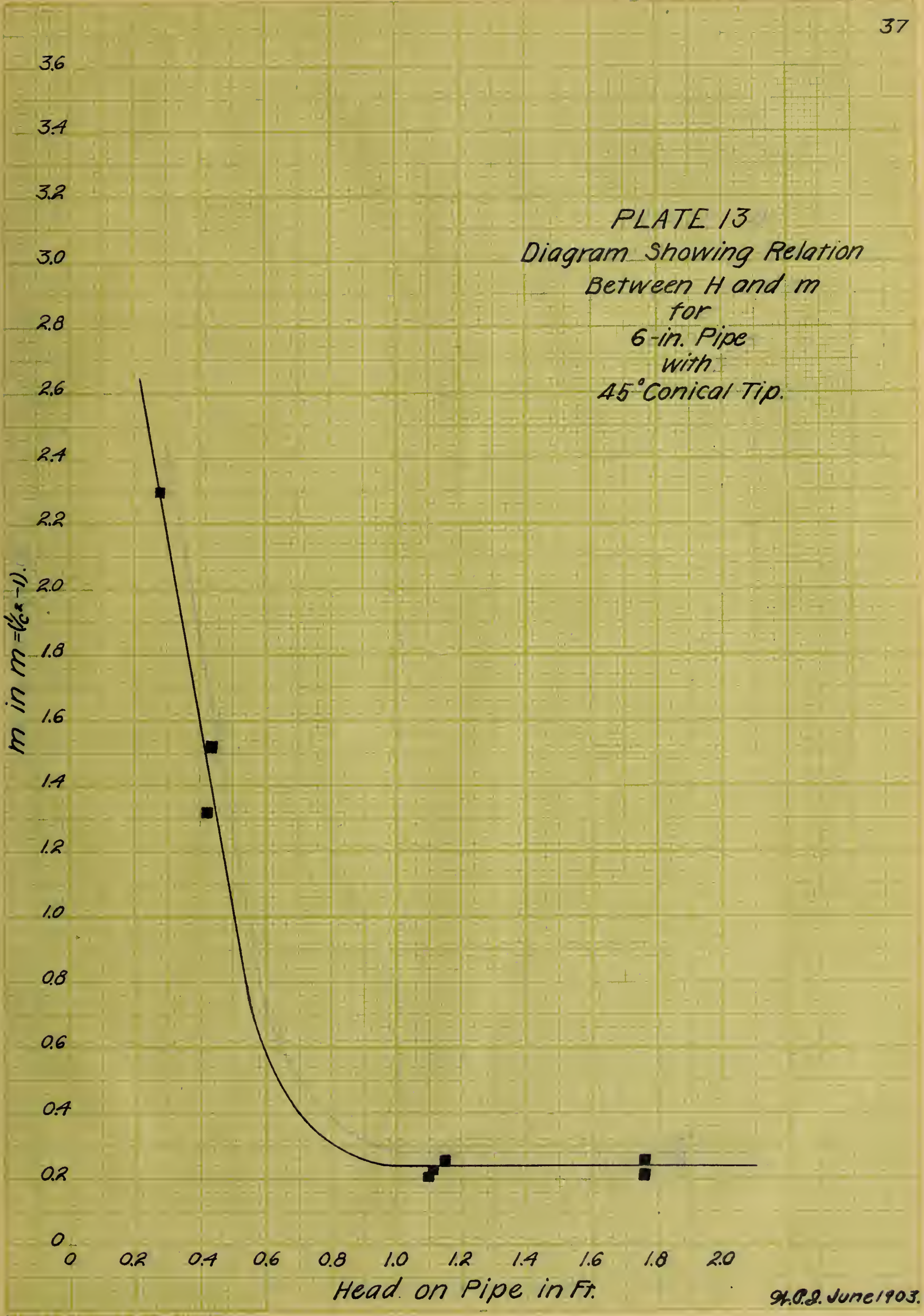

PLATE 13
Diagram Showing Relation
Between H and m
for
6-in. Pipe
with
45° Conical Tip.

H.C.G. June 1903.

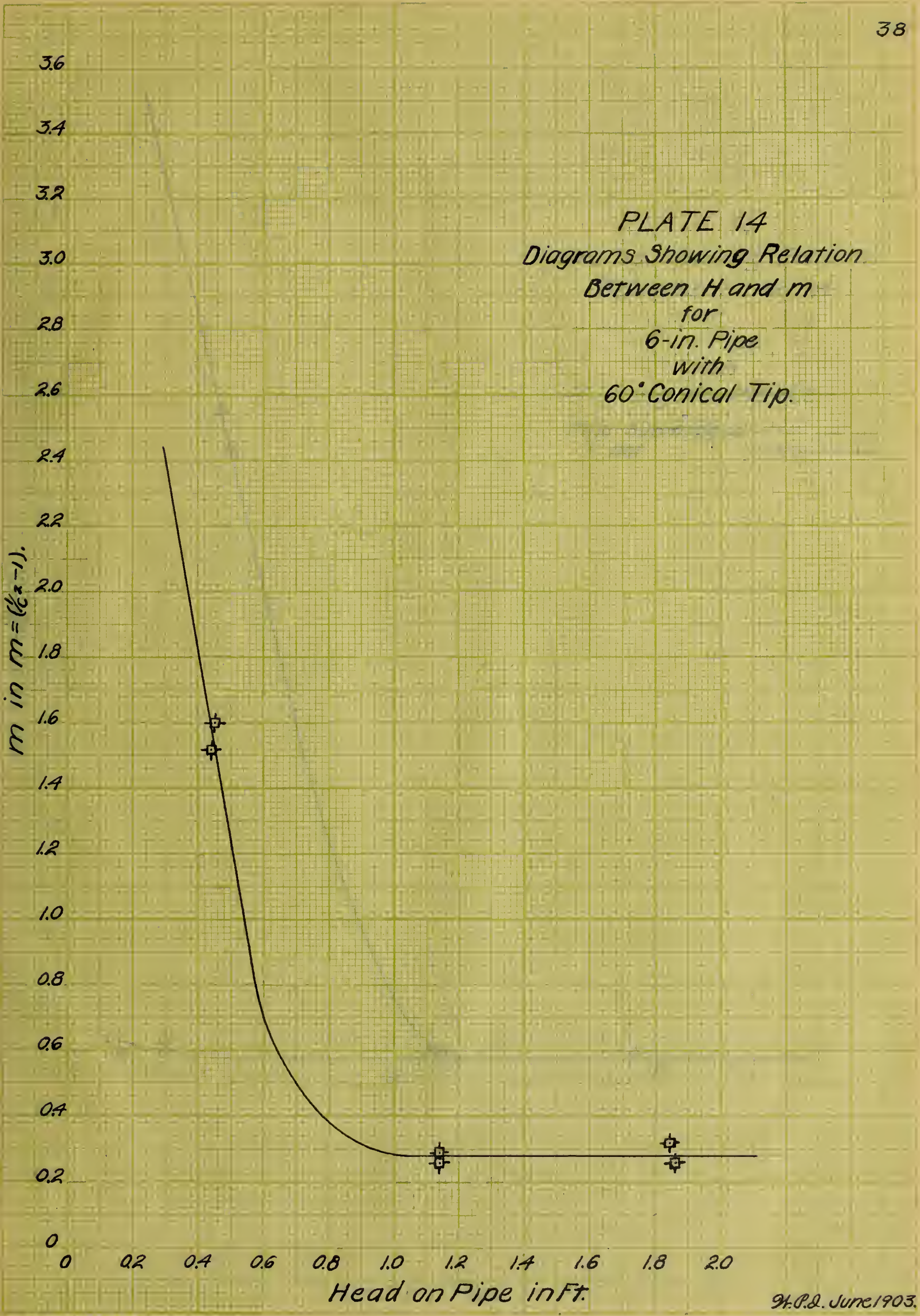

PLATE 14
Diagrams Showing Relation
Between H and m
for
6-in. Pipe
with
60° Conical Tip.

H.P.D. June 1903.

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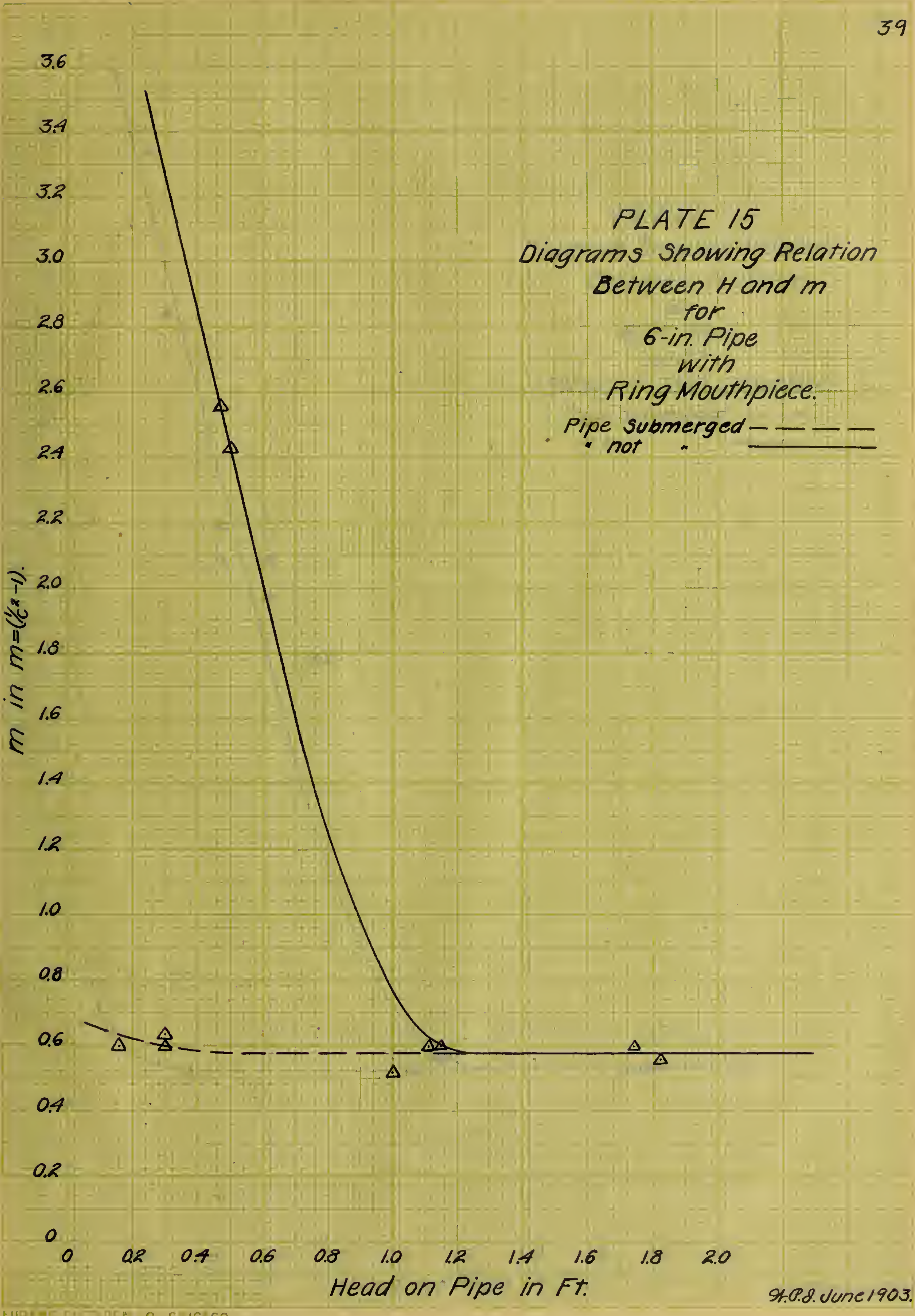

PLATE 15

Diagrams Showing Relation Between H and m for 6-in. Pipe with Ring Mouthpiece.

H.O.S. June 1903.

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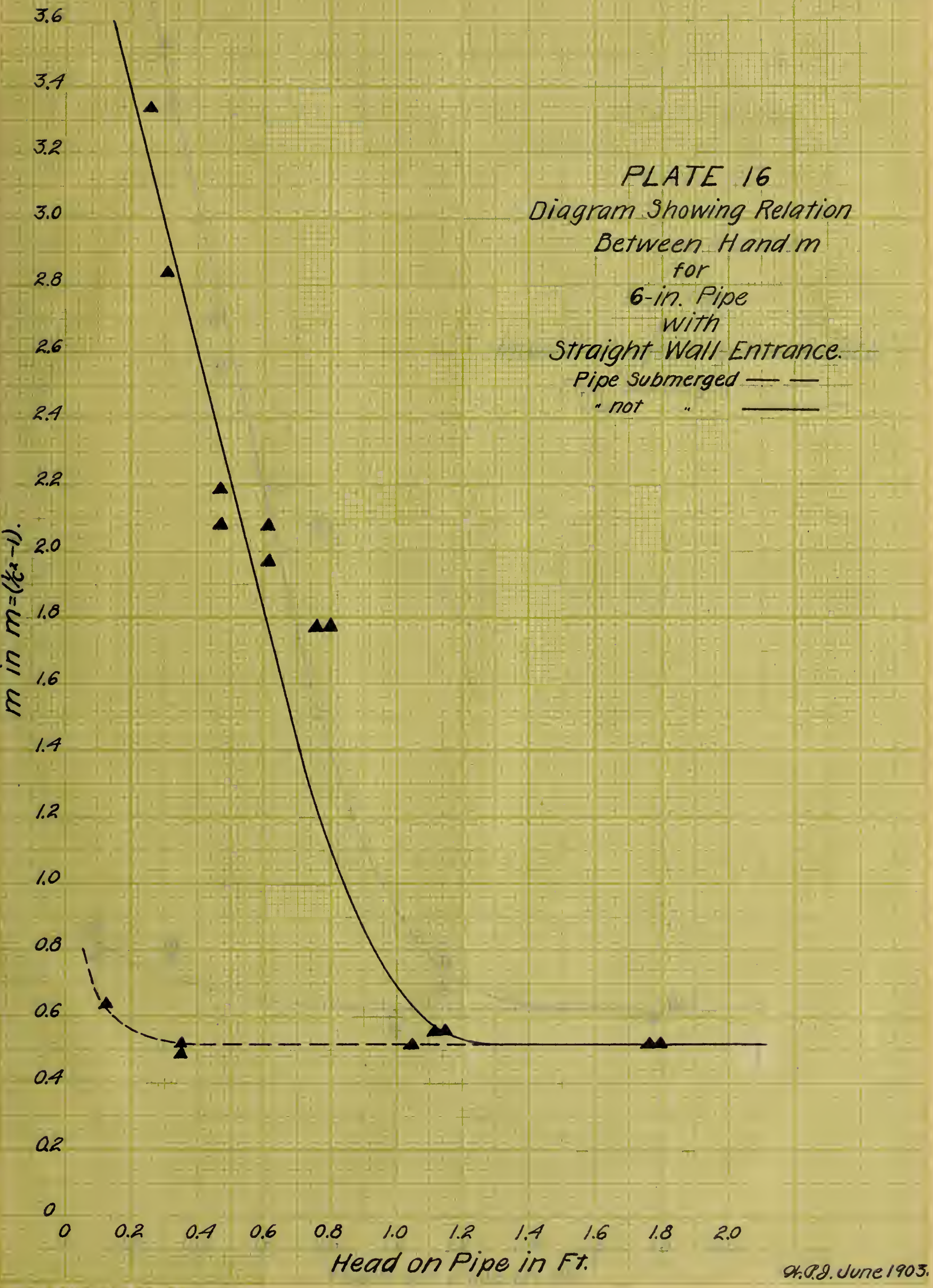

PLATE 16

Diagram Showing Relation
Between H and m
for
6-in. Pipe
with
Straight Wall Entrance.

H.O.J. June 1903.

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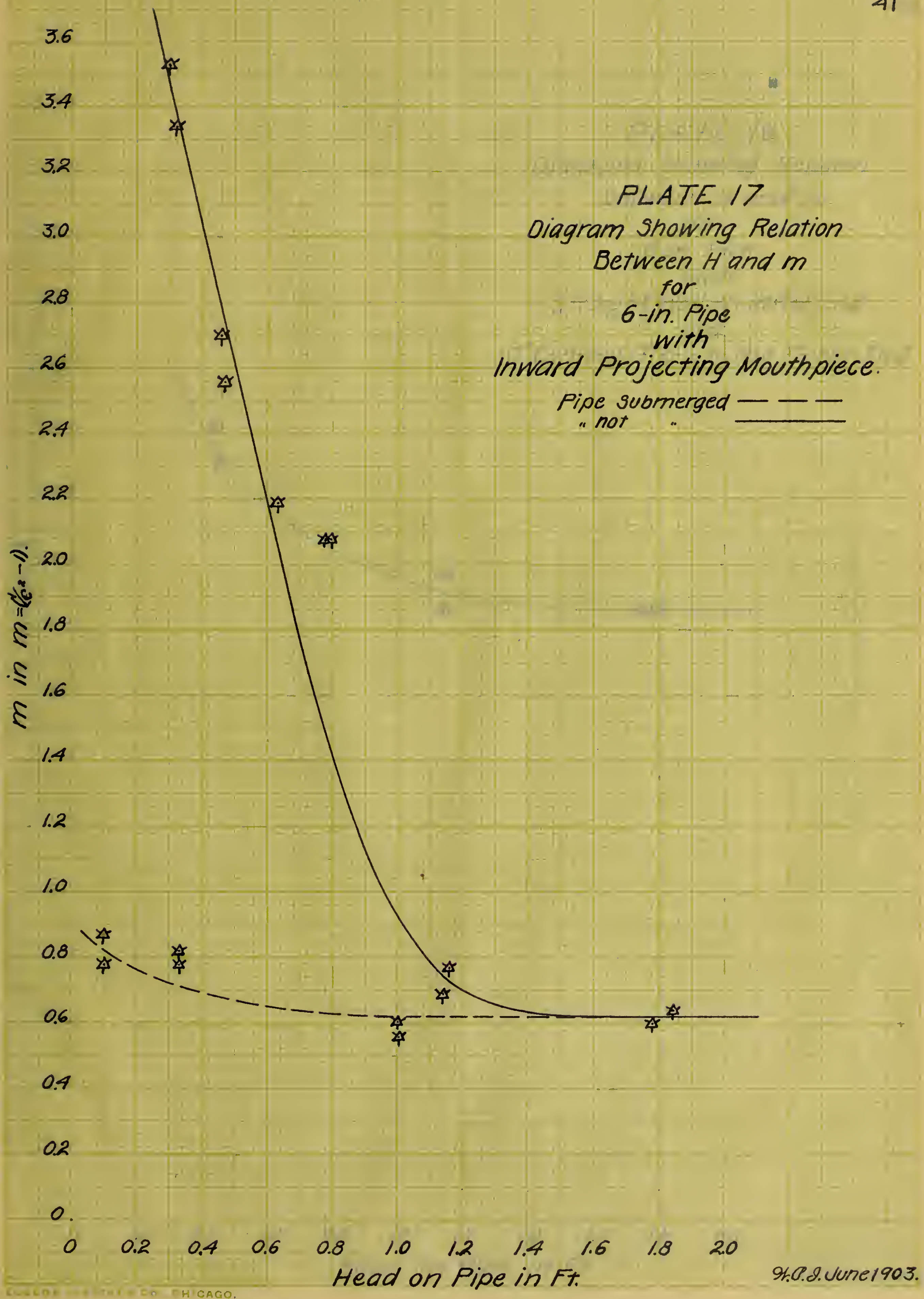

PLATE 17
Diagram Showing Relation
Between H and m
for
6-in. Pipe
with
Inward Projecting Mouthpiece.

H.C.J. June 1903.

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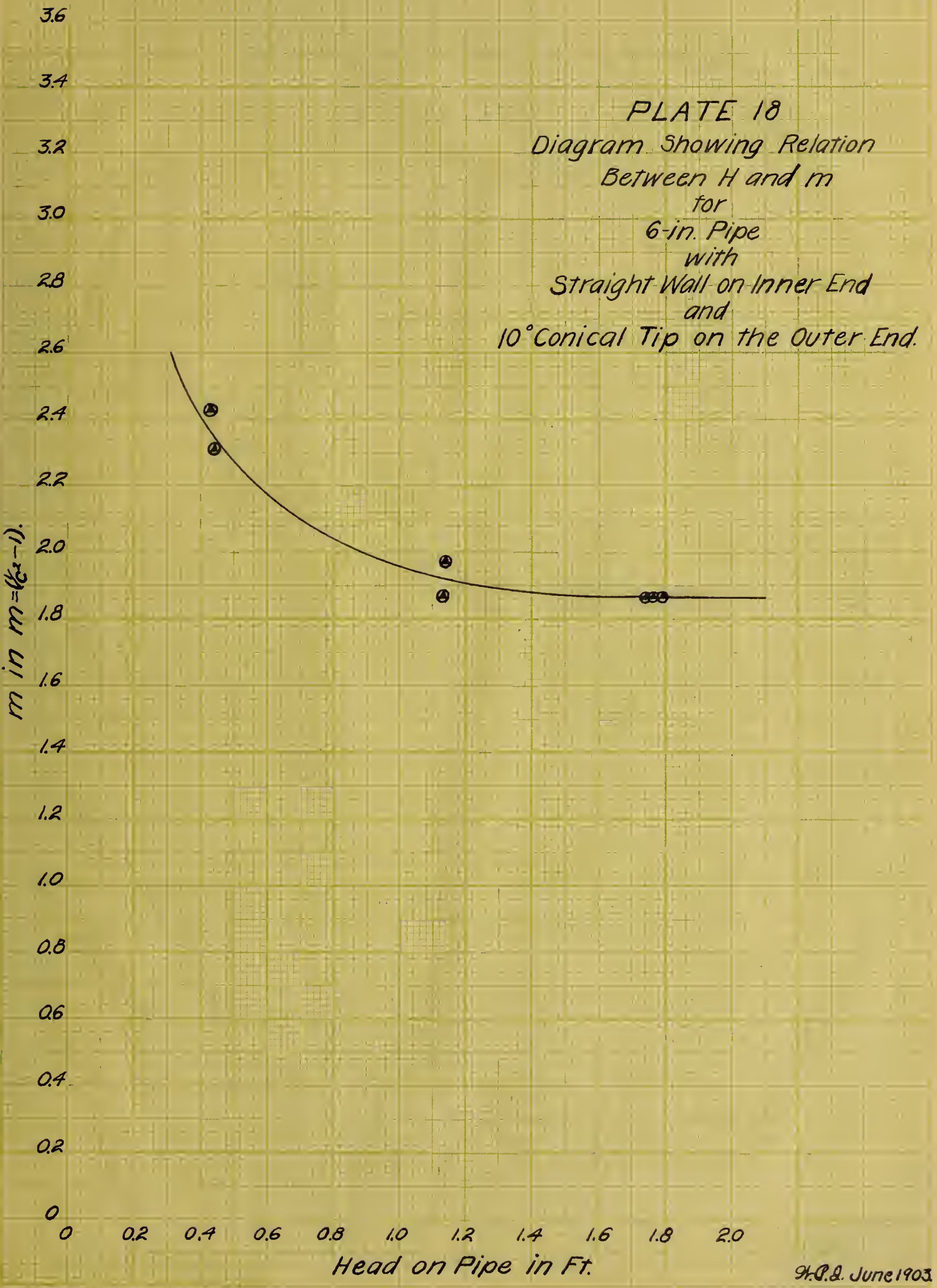

PLATE 18
Diagram Showing Relation
Between H and m
for
6-in. Pipe
with
Straight Wall on Inner End
and
10° Conical Tip on the Outer End.

H.C.D. June 1903

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